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Walters

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(45) **Date of Patent: Jan. 29, 2013**

(54) **ROTARY PRESSURE PRODUCTION DEVICE**

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(51) **Int. Cl.**
F04B 27/10 (2006.01)
F04B 35/01 (2006.01)
H02K 7/18 (2006.01)

(52) **U.S. Cl.** **417/273**; 417/540; 417/545; 417/547; 138/30

(58) **Field of Classification Search** 417/273, 417/470, 540, 545, 547; 138/30
See application file for complete search history.

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(57) **ABSTRACT**

A rotary pressure production turbine for pressurizing a hydraulic fluid is disclosed comprising a plurality of piston assemblies. Each piston assembly comprises a hollow needle piston shaft having through which hydraulic fluid is moved from a low pressure volume to a high pressure volume as the piston shaft moves in a first direction. A rotary actuator actuates each piston shaft. From the high pressure volume, hydraulic fluid is moved to a common high pressure header and delivered to an aspirated accumulator where the fluid can be stored and subsequently utilized. In some embodiments, the fluid is utilized to operate an electric generator for use in a hybrid-electric vehicle. In some embodiments, the rotary actuator is driven by an internal combustion engine, while in others the rotary actuator is driven by a vehicle drive train in a regenerative braking application.

19 Claims, 13 Drawing Sheets

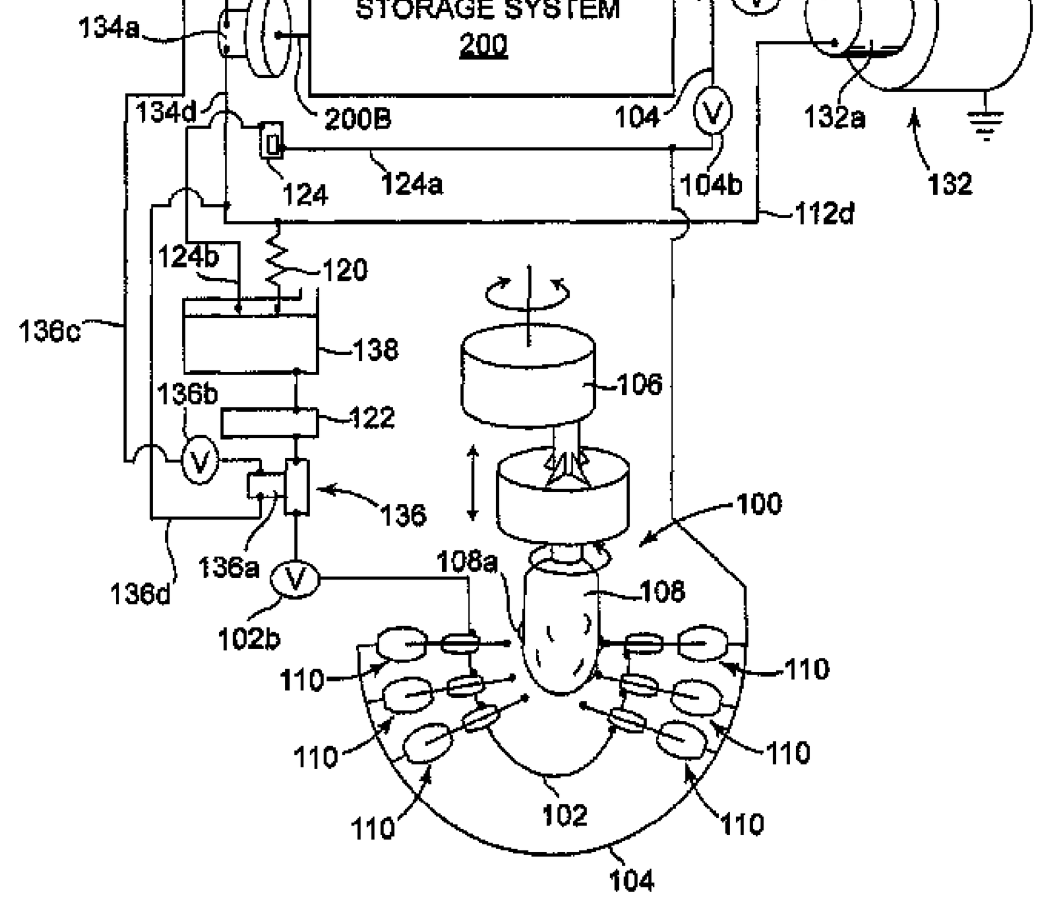
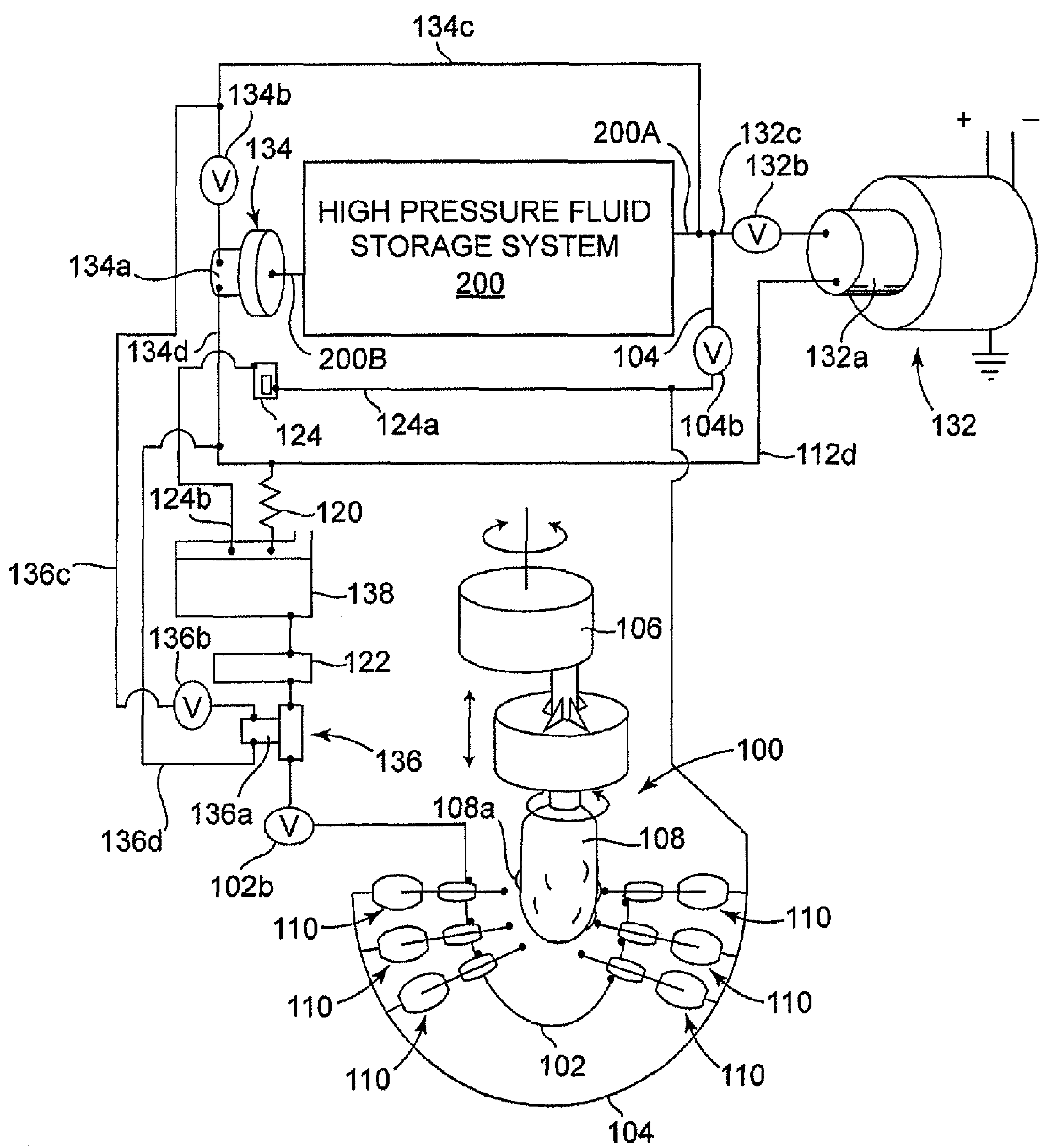


FIG. 1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104b
134d
124
124a
112d
124b
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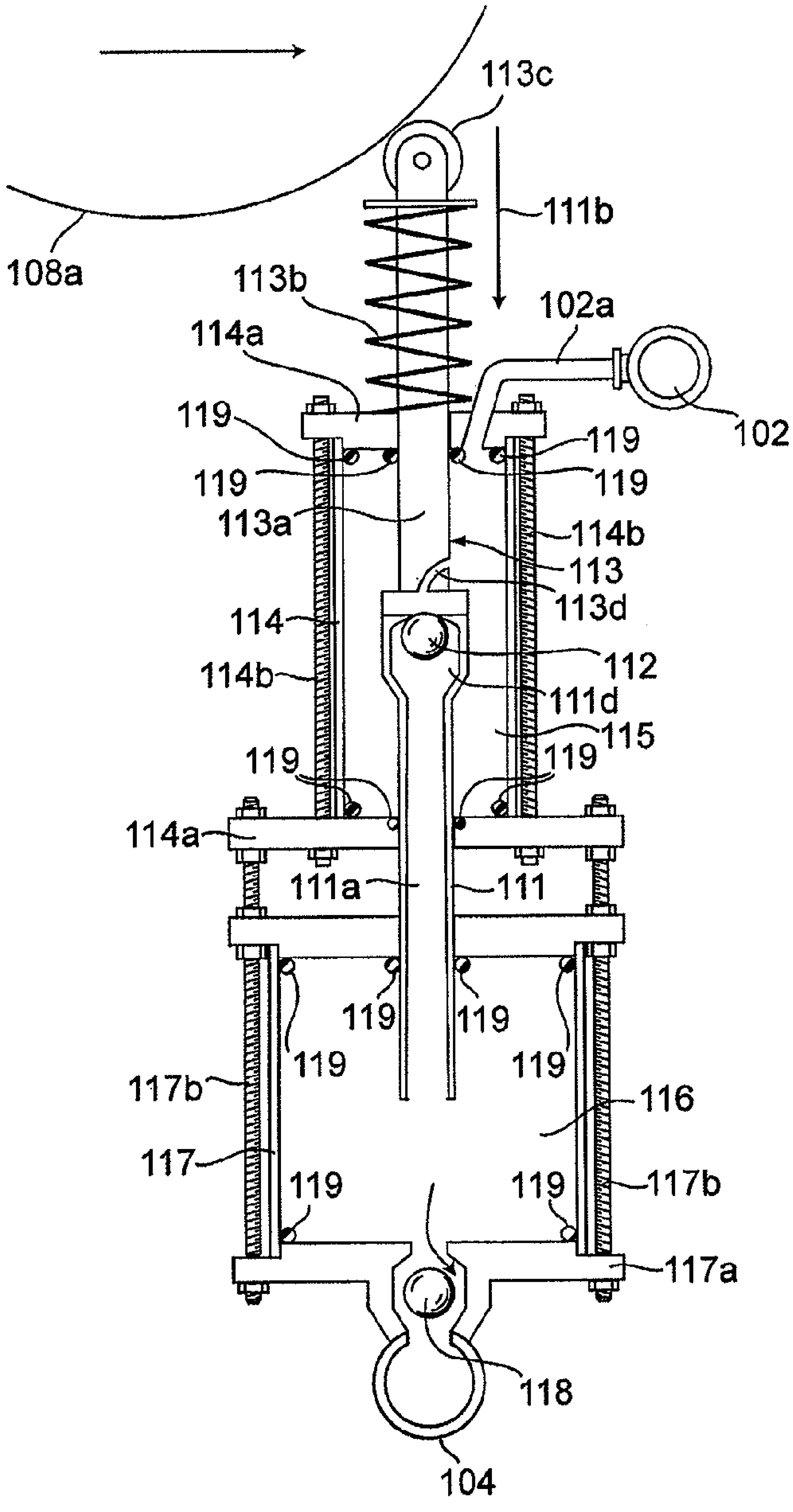
136d
102b
110
102
104

FIG. 2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111d
115
119
119
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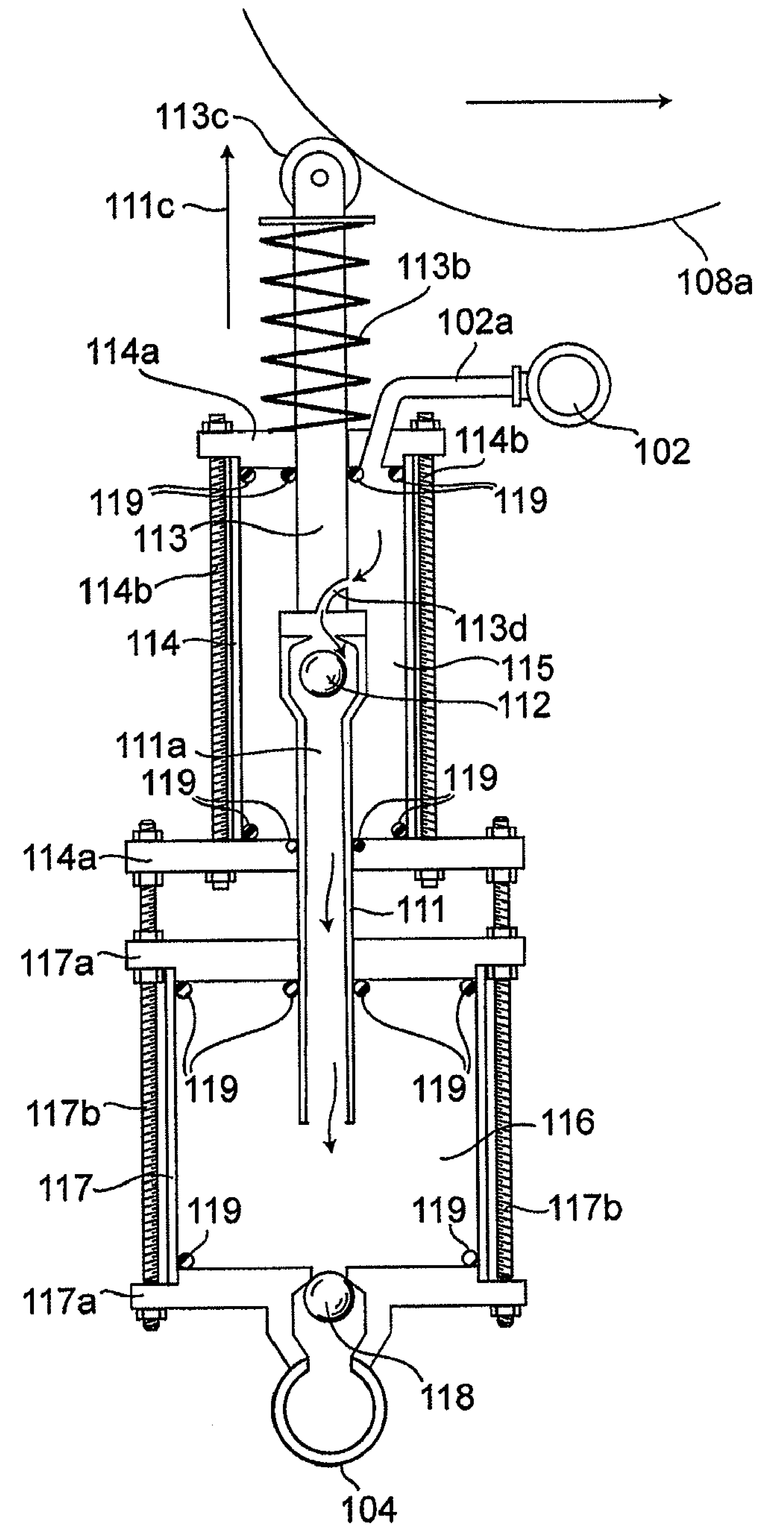
119
119
119
119
117b
116
117
119
119
117b
117a
118
104

FIG. 3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119
117b
116
117
119
119
117b
117a
118
104

FIG. 4A

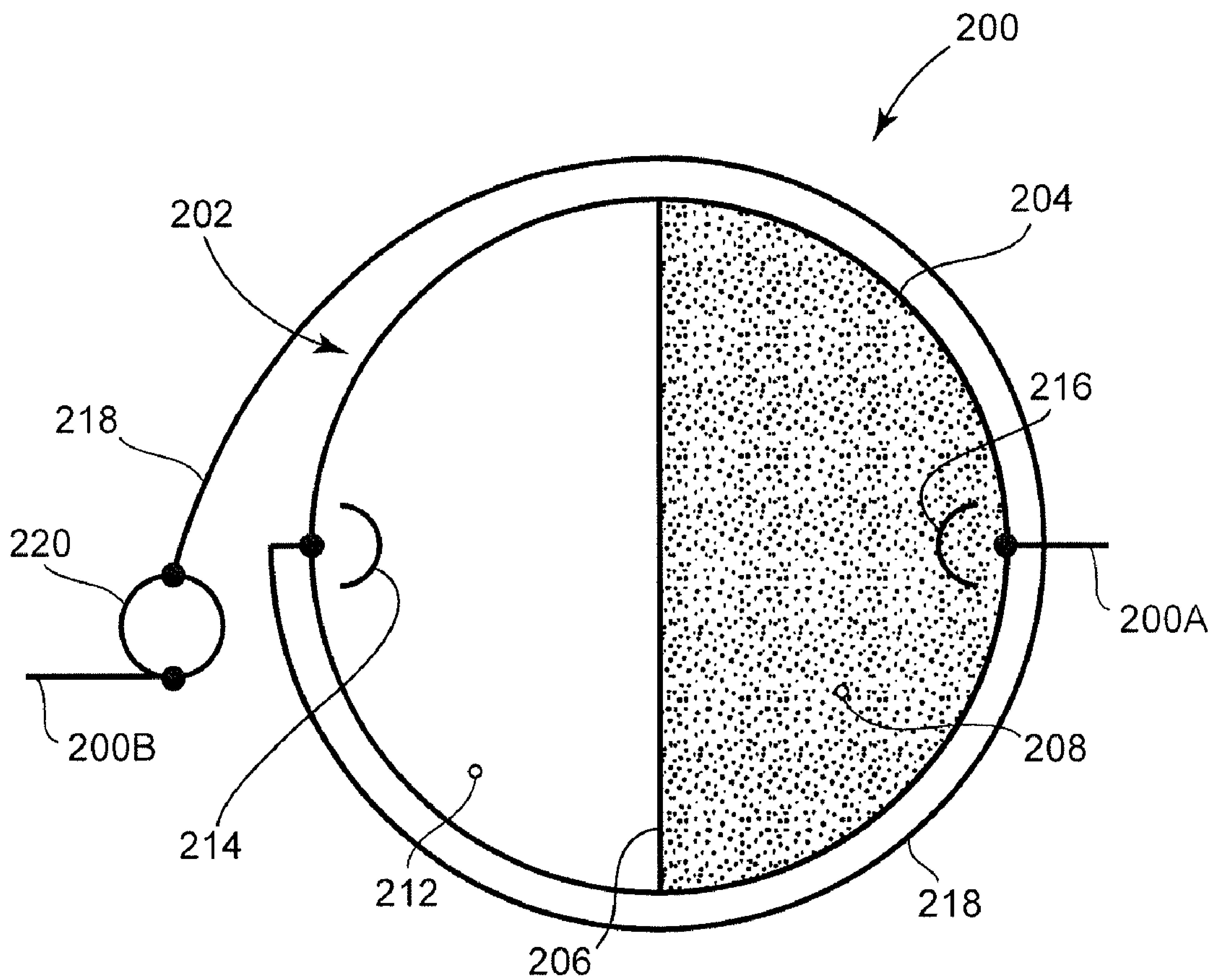

FIG. 4B

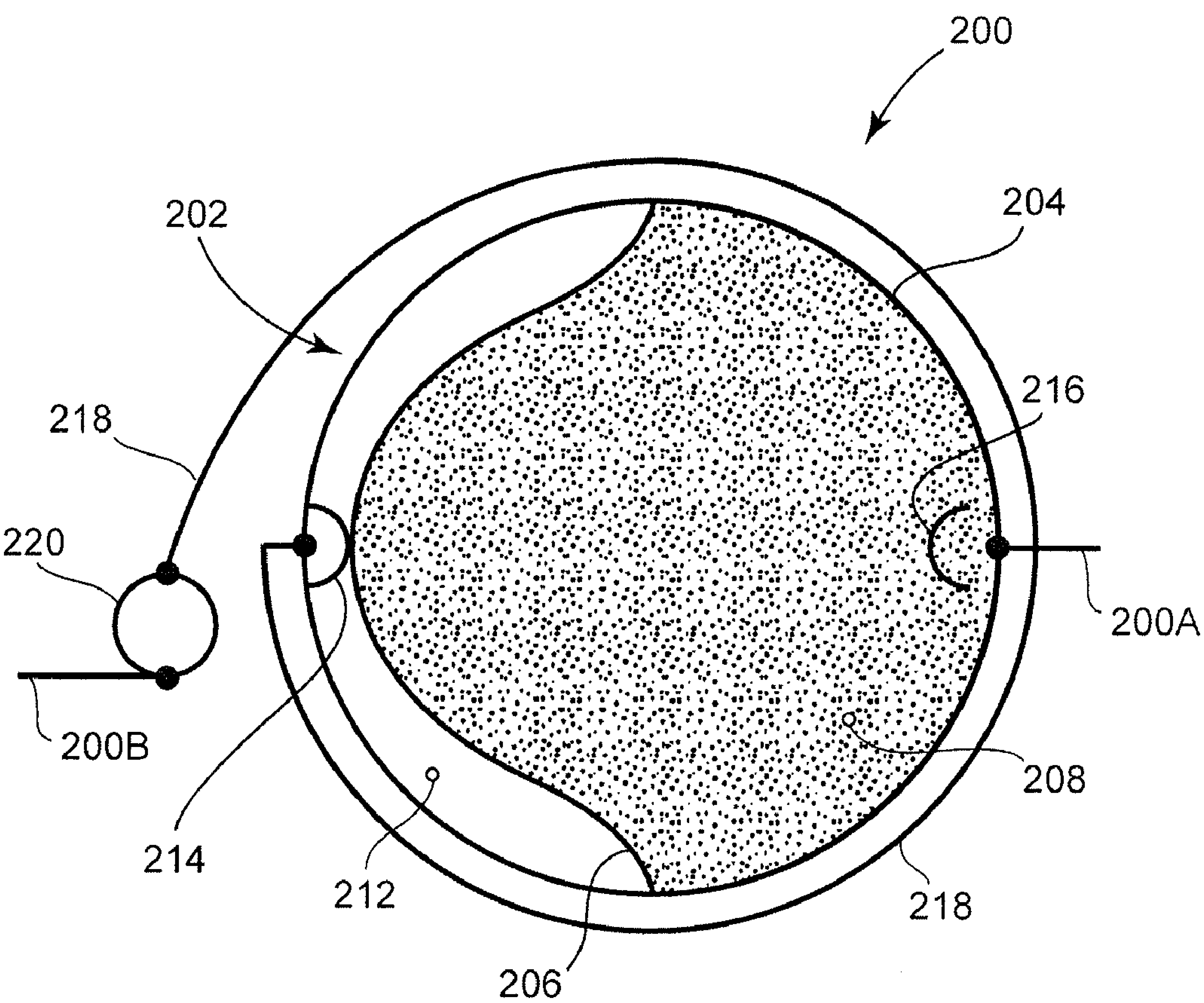

FIG. 4C

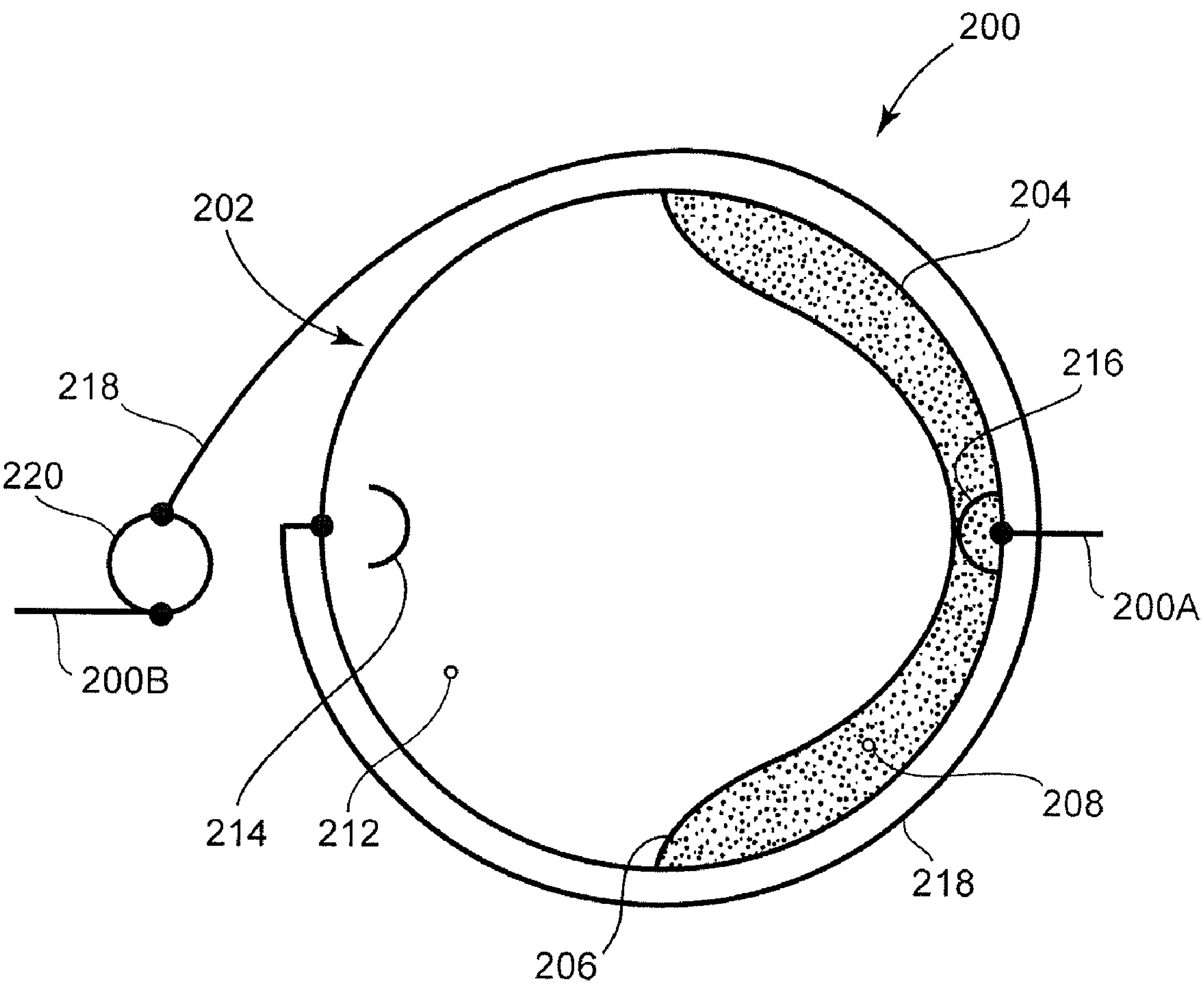

FIG. 5A

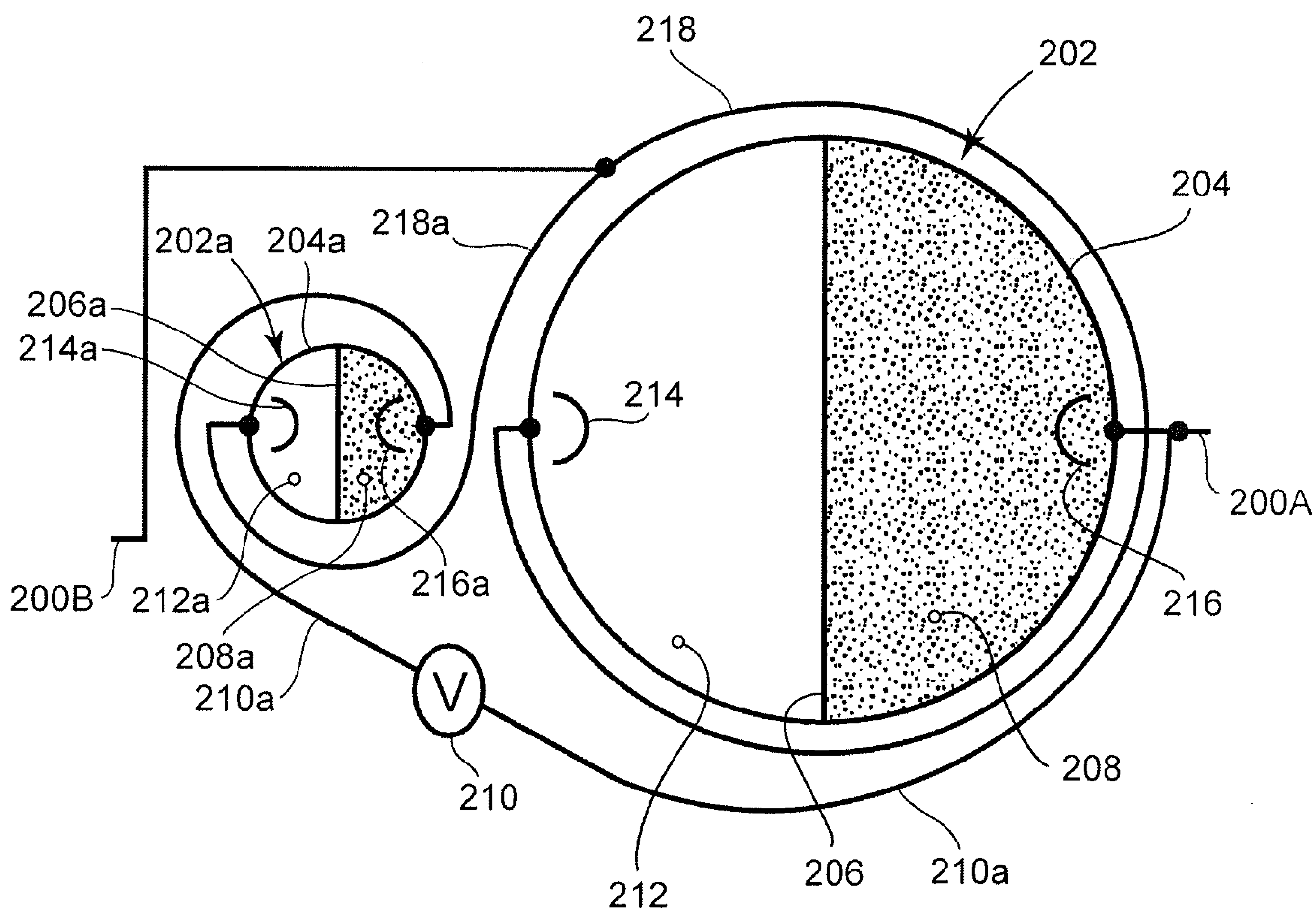
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FIG. 5B

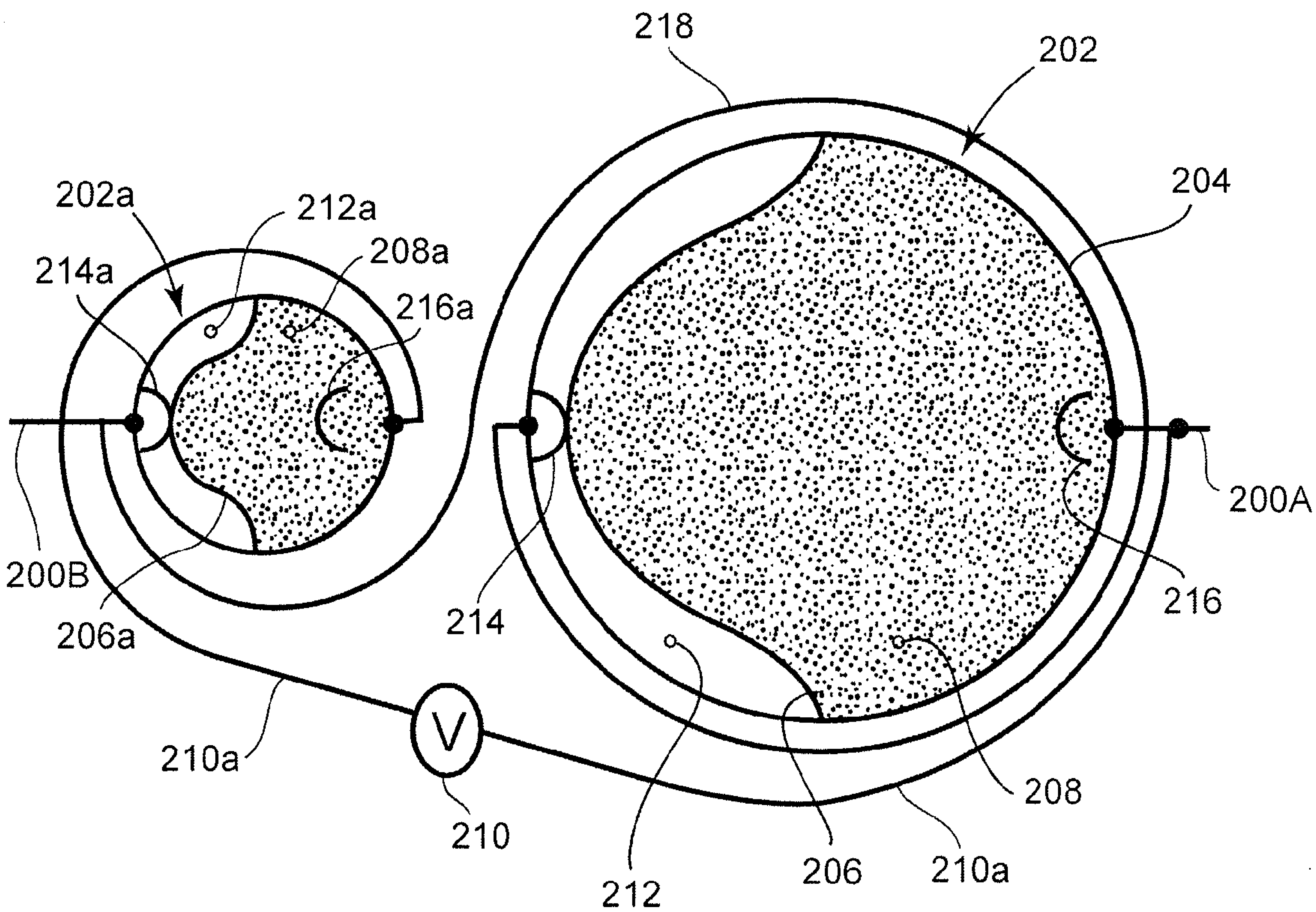
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FIG. 5C

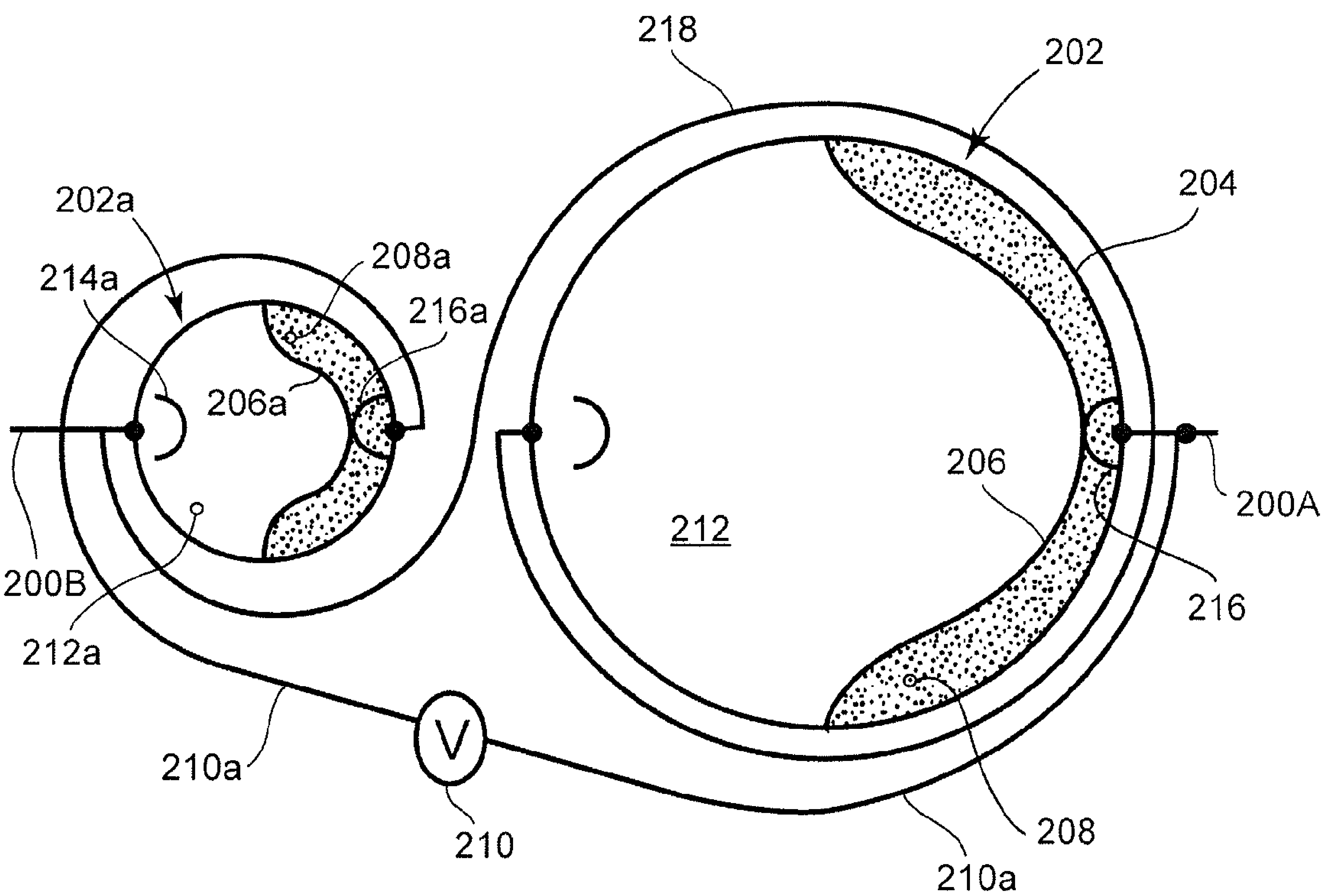
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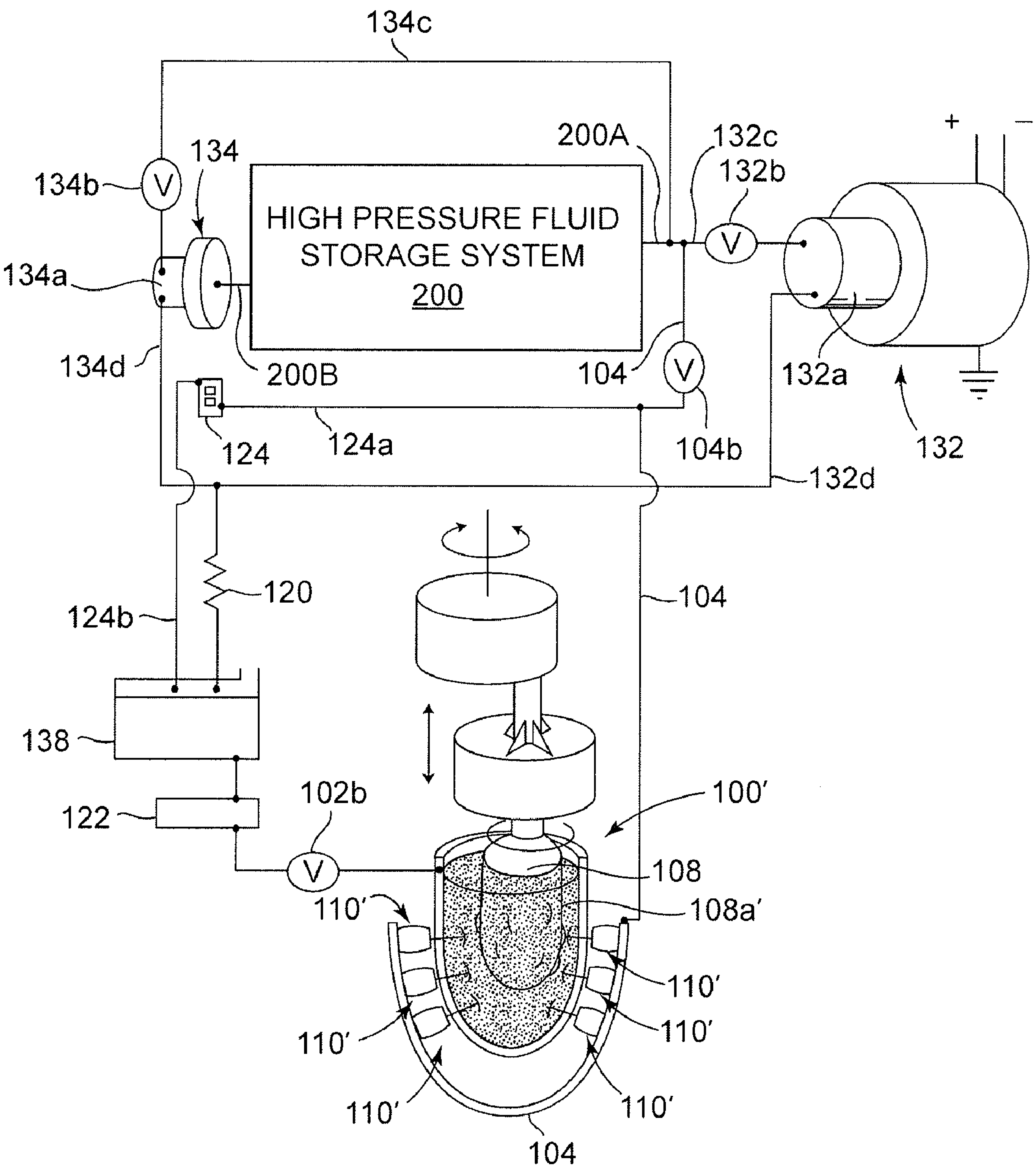
FIG. 6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200A
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132b
+
−
134
134b
V
HIGH PRESSURE FLUID
STORAGE SYSTEM
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V
134d
200B
104
V
132a
124
124a
104b
132
132d
120
104
124b
138
122
102b
V
100′
108
110′
108a′
110′
110′
110′
110′
110′
104

FIG. 7

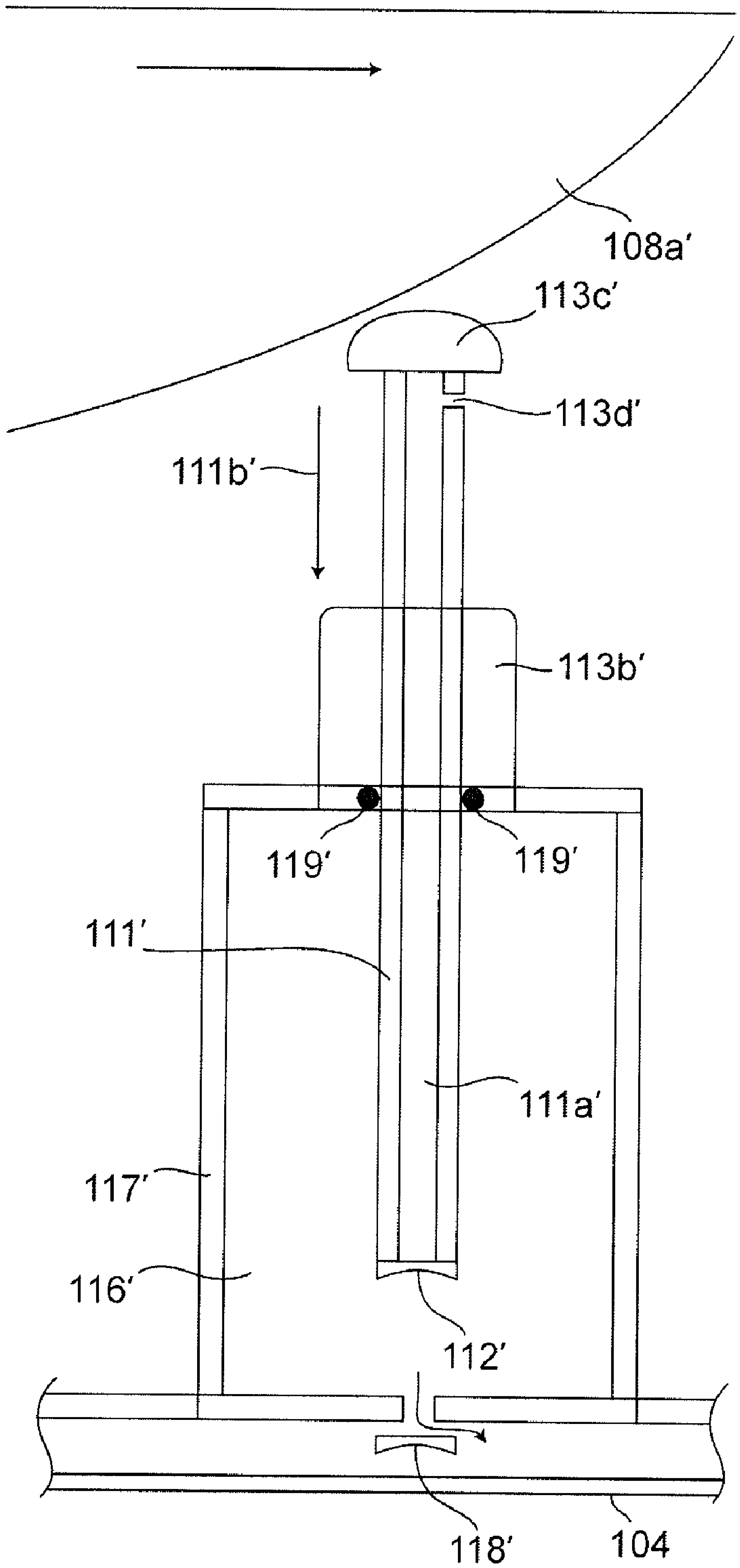


FIG. 8

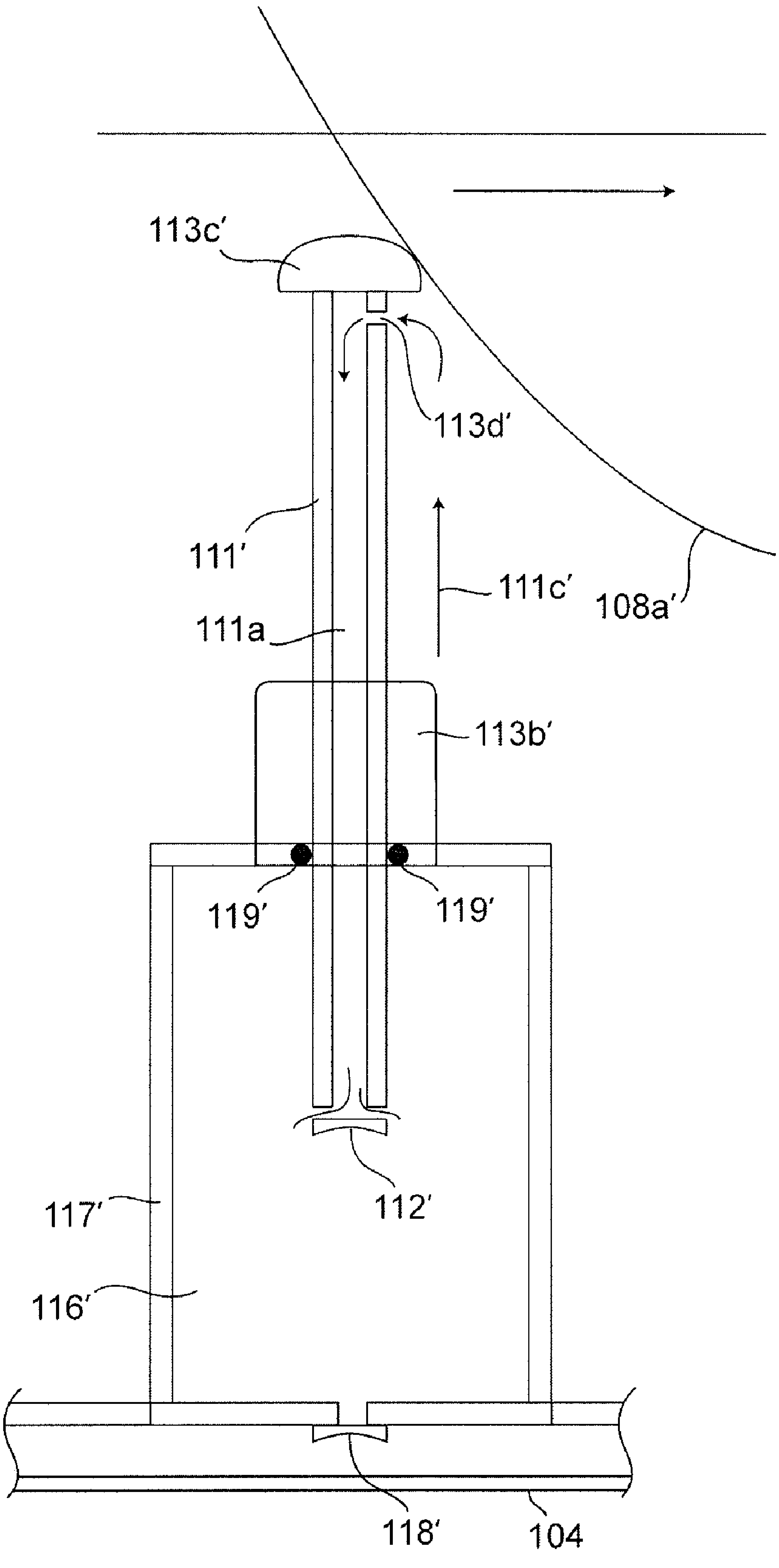
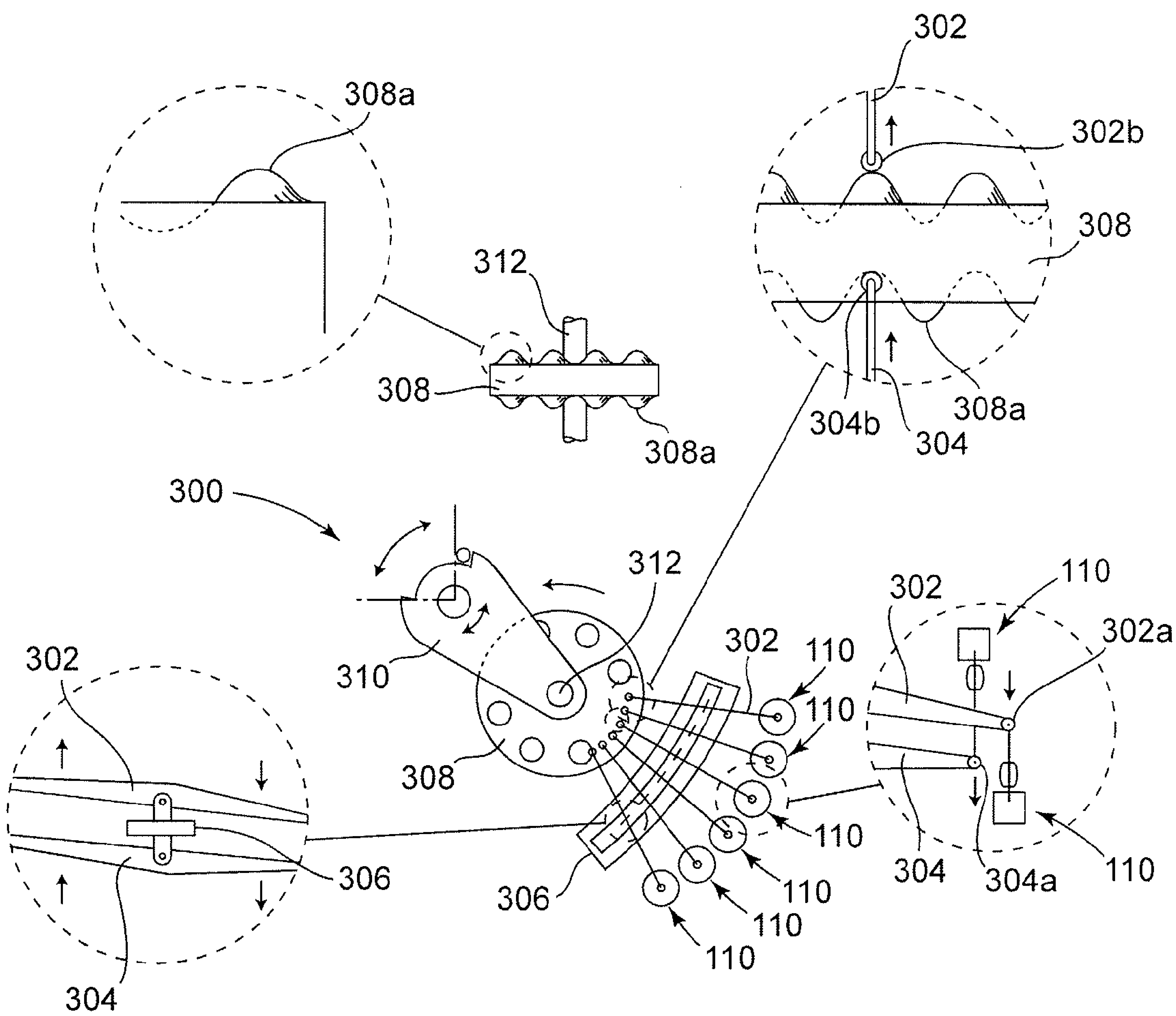


FIG. 9



308a
312
308
308a
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302b
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304b
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308a
300
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110
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302a
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302
306
304
306
110
110
110
110
110
304
304a
110

ROTARY PRESSURE PRODUCTION DEVICE

CROSS REFERENCE TO RELATED APPLICATIONS

This application claims priority under 35 U.S.C. §119(e) to U.S. Provisional Application 61/205,621, filed Jan. 23, 2009. The complete disclosure of U.S. Provisional Application 61/205,621 is hereby incorporated in its entirety.

BACKGROUND

This application relates to hydraulic pressure production devices and systems in which they can be utilized. Methods for the production of pressurized hydraulic fluid are also disclosed.

SUMMARY

A pressure production system for pressurizing a hydraulic fluid that utilizes a rotary pressure production device is disclosed. The device system includes a plurality of piston assemblies, each of which has a hollow needle piston shaft through which hydraulic fluid is moved from a low pressure volume into a high pressure volume as the piston shaft moves in a first direction. The piston assemblies discharge fluid into a common high pressure header from the high pressure volume, and further include a vacuum check valve in fluid communication with the low and high pressure volumes. In operation, the vacuum check valve is closed as the hollow piston shaft moves in the first direction and open as the hollow piston shaft moves in a second, opposite direction. A discharge check valve can also be provided that is in fluid communication with the first high pressure volume and the high pressure header, the discharge check valve being open when hollow piston shaft is moving in the first direction and closed when shaft is moving in the second direction. The device system also includes a rotary piston actuator that moves each hollow piston shaft in the first direction when the rotary piston actuator is rotating.

The rotary pressure production device system can be used in a larger system, such as in a hybrid over electric vehicle. In such an application, the device system can be driven by an internal combustion engine and the second high pressure fluid volume can take the form of a header assembly combined with a fluid storage aspirated accumulator where the pressurized hydraulic fluid can be stored until needed. In such an application, the accumulator can be pre-pressurized by a gas behind a diaphragm wall such that the stored hydraulic fluid is maintained at a minimum operating pressure. Pressurized hydraulic fluid from the accumulator can be used to power a hydraulic motor coupled to an electric generator to provide electric power to the vehicle. Additionally, the pressurized hydraulic fluid can also be used to power a hydraulic motor coupled to a gas compressor, such as an air compressor for pre-pressurizing the accumulator. A number of check valves can also be provided within the accumulator to prevent rupturing of the diaphragm wall.

Additionally disclosed is a method for pressurizing hydraulic fluid, the method comprising the steps of (a) drawing hydraulic fluid from a low pressure volume into a hollow needle piston shaft; (b) moving the hollow needle piston shaft and the hydraulic fluid within the hollow needle piston shaft in a first direction and into a high pressure volume; (c) closing fluid communication between the high pressure volume and the low pressure volume; (d) compressing the hydraulic fluid in the high pressure volume with the hydraulic fluid in the hollow needle piston such that the fluid is moved into a common high pressure header, the header being in fluid communication with the high pressure volume; (e) moving the hollow needle piston shaft in a second direction opposite the first direction; (f) closing fluid communication between the high pressure volume and the high pressure header. The method can also be performed such that the steps are repeated continuously and with a plurality of hollow needle piston shafts in either a synchronized manner, or at different times.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. **1** is a schematic of a first embodiment of a system for producing, storing and utilizing pressurized hydraulic fluid, the system including a rotary pressure production device and a high pressure fluid storage system.

FIG. **2** is a schematic of a first embodiment of a piston assembly in a first state for use in the rotary pressure production device of FIG. **1**.

FIG. **3** is a schematic of a first embodiment of a piston assembly in a second state for use in the rotary pressure production device of FIG. **1**.

FIG. **4**A is a schematic of a first embodiment of the high pressure fluid storage system of FIG. **1** in a first state.

FIG. **4**B is a schematic of the high pressure fluid storage system of FIG. **4***a* in a second state.

FIG. **4**C is a schematic of the high pressure fluid storage system of FIG. **4***a* in a third state.

FIG. **5**A is a schematic of a second embodiment of the high pressure fluid storage system of FIG. **1** in a first state.

FIG. **5**B is a schematic of the high pressure fluid storage system of FIG. **5***a* in a second state.

FIG. **5**C is a schematic of the high pressure fluid storage system of FIG. **5***a* in a third state.

FIG. **6** is a schematic of a second embodiment of a system for producing, storing and utilizing pressurized hydraulic fluid, the system including a rotary pressure production device and a high pressure fluid storage system.

FIG. **7** is a schematic of a first embodiment of a piston assembly in a first state for use in the rotary pressure production device of FIG. **6**.

FIG. **8** is a schematic of a first embodiment of a piston assembly in a second state for use in the rotary pressure production device of FIG. **6**.

FIG. **9** is a schematic of a first embodiment of a rotary piston actuator assembly.

DETAILED DESCRIPTION

This disclosure relates to systems for the production of pressurized hydraulic fluid. FIG. **1** represents a system in which pressurized hydraulic fluid is produced, stored and utilized. As shown, pressurized hydraulic fluid is produced by a rotary pressure production device **100** that can be delivered to one or more end use devices. Examples of end use devices are linear actuators (i.e. hydraulic cylinders), rotary actuators, brakes, hydrostatic transmissions and hydraulic motors. Hydraulic motors are particularly useful for a variety of purposes similar to those applicable for electric motors and internal combustion engines. For example, hydraulic motors can be used to drive electric generators, gas compressors, fluid pumps, vehicle drive trains, or for any application where rotary power is desired.

In the embodiment shown in FIG. **1**, a rotary pressure production device **100** is disclosed. Rotary pressure production device **100** is for producing high pressure hydraulic fluid from a low pressure fluid source. By use of the term "high pressure" it is generally meant to include pressures above 100 pounds per square inch (psi), and more preferably pressures above 1,000 psi. By the use of the term "low pressure" it is generally meant to include all pressures at or below 100 psi, including negative pressures. Many variations of a rotary pressure production device **100** exist without departing from the concepts disclosed herein. In the particular embodiment shown in FIG. **1**, rotary pressure production device **100** includes a plurality of piston assemblies **110** that, when actuated, move hydraulic fluid from a common low pressure header **102** to a common high pressure header **104**. As shown, the piston assemblies **110** are actuated by a drive source **106** having a rotary actuator **108** that engages the piston assemblies **110** via cam lobes **108***a*. Drive source **106** can be an internal combustion engine, the drive train of a vehicle, or any other rotating power source. In the exemplary embodiment shown, drive source **106** is an internal combustion engine and rotary actuator **108** is configured to eccentrically rotate such that the piston assemblies **110** are actuated out of phase. By actuating piston assemblies **110** out of phase with each other, a more even production of pressurized hydraulic fluid can be accomplished.

As shown in FIG. **1**, high pressure hydraulic fluid is delivered to several end use devices including electric generator **132**, gas compressor **134**, hydraulic fluid pump **136** and high pressure fluid storage system **200**. Electric generator **132** can be used to supply electrical power for a variety of applications, including an electric motor in a hybrid-electric vehicle. Gas compressor **134** is for aspirating the high pressure fluid storage system **200** with a gas, such as compressed air. Hydraulic fluid pump **136** is for delivering low pressure hydraulic fluid to the common low pressure header **102** from the low pressure fluid reservoir **138** where hydraulic fluid is returned after being exhausted by the end use devices. Pump **136** can deliver a variety of pressures. However, a range of 10 pounds per square inch (psi) to 100 psi is the most likely delivery pressure for the disclosed application. High pressure fluid storage system **200**, discussed later, is for storing high pressure hydraulic fluid until it is needed by the end use devices.

As shown, generator **132**, compressor **134** and pump **136** are each driven by a hydraulic motor **132***a*, **134***a*, **136***a*. Each of the motors **132***a*, **134***a*, **136***a* is supplied with high pressure hydraulic fluid from high pressure header **104** via lines **132***c*, **134***c* and **136***c*, respectively. The power output for each of the motors **132***a*, **134***a*, **136***a* is selectively controlled by a corresponding actuated valve **132***b*, **134***b*, **136***b*. Once the hydraulic fluid is used and exhausted from the hydraulic motors **132***a*, **134***a*, **136***a*, the fluid is returned via lines **132***d*, **134***d*, **136***d* to a low pressure reservoir **138** where the fluid can be processed and provided back to the device **110**. One example of processing that can be performed on the fluid is the use of an oxygen scrubber and contaminant removal filter **122** disposed between the reservoir **138** and the device **110**. The oxygen scrubber is particularly useful where large size differentials exist between housing **117** (discussed later) and shaft **111** (discussed later) as the fluid should be maintained as incompressible as possible. The exhausted fluid can also be cooled by a heat exchanger **120** prior to being returned to the reservoir **138**. Additionally, in the event that none of the end use devices **132**, **134**, **136**, **200** can accept additional high pressure hydraulic fluid at a point in time where the device **110** is still producing high pressure hydraulic fluid, the fluid can be passed through a pressure reducing valve (PRV) **124** and returned to the reservoir **138** via lines **124***a*, **124***b*. Valve **104***b* can also shut to aid in directing fluid to the PRV **124**. However, it should be understood that the device **110** is optimally controlled to minimize the need for use of the pressure reduction valve **122**, such as by modulating the rotating speed of the drive source **106**.

Referring to FIGS. **2** and **3**, an exemplary embodiment of a single piston assembly **110** of FIG. **1** is shown. Many variations of piston assemblies exist without departing from the concepts presented herein. The following paragraphs describe the various aspects and features of piston assembly **110**.

In the embodiment shown in FIGS. **2**-**3**, piston assembly **110** includes a hollow needle shaft **111** through which hydraulic fluid is forced from a low pressure volume **115** defined by housing **114** and end plates **114***a* to a high pressure volume **116** defined by housing **117** and end plates **117***a*. Additionally, end plates **114***a*, **117***a* are secured to housings **114**, **117** by retaining rods **114***b*, **117***b*, respectively. As shown, housings **114**, **117** are cylindrical in shape, however, housings **114**, **117** could also be spherical, conical or virtually any other shape. Some shapes allow for maximization of the surface area of housings **114**, **117** which advantageously increases the heat dissipation rate of the hydraulic fluid. Within an expanded portion **111***d* within the hollow portion **111***a* of shaft **111**, a vacuum check valve **112** is disposed. Valve **112** is for enabling shaft **111** to act as a piston for forcing hydraulic fluid into the high pressure volume **116**. Additionally, the expanded portion **111***d* of shaft **111** allows for lower flow resistance of the hydraulic fluid.

Piston assembly **110** also includes an actuator shaft **113** connected to the hollow needle shaft **111**. Actuator shaft **113** is for moving hollow needle shaft **111** in a first direction **111***b* and a second, opposite direction **111***c*. FIG. **2** shows actuator shaft **113** and needle shaft **111** moving in the first direction while FIG. **3** shows actuator shaft **113** and needle shaft **111** moving in the second direction. Actuator shaft **113** can be configured in various ways to accomplish this function. In the exemplary embodiment shown in FIGS. **2**-**3**, actuator shaft **113** includes a main stem portion **113***a*, a medium duty return spring **113***b*, a strike head **113***c* having a rotating wheel and an inlet port **113***d*. When the strike head **113***c* comes into contact with a cam lobe **108***a* of rotary actuator **108**, the actuator shaft **113** and the hollow needle shaft **111** are moved in the first direction **111***b*. When cam lobe **108***a* is no longer in contact strike head **113***c*, the return spring **113***b* causes the actuator shaft **113** and the hollow needle shaft **111** to move in the second direction **111***c*. While the main stem **113***a* is moving in the second direction, hydraulic fluid flows from the low pressure volume **115** into the hollow portion **111***a* of the hollow needle shaft **111**. Although only one inlet port **113***d* is shown for the purpose of clarity, a plurality of ports **113***d* is advantageous in reducing flow resistance of the hydraulic fluid into the hollow needle shaft **111**.

Another aspect of piston assembly **110** is vacuum check valve **112**. Vacuum check valve **112** is for simultaneously preventing hydraulic fluid from moving from the high pressure volume **116** to the low pressure volume **115** as the shaft **111** is moving in the first direction **111***b*. This operation allows for hollow needle shaft **111** to act as a piston to force hydraulic fluid within the shaft **111** into the high pressure volume, thereby increasing the pressure of the fluid in the high pressure volume. Multiple configurations exist for vacuum check valve **112** without departing from the concepts presented herein. In the embodiment shown in FIGS. **2**-**3** vacuum check valve **112** is a ball valve disposed within the hollow portion **111***a* of hollow needle shaft **111** and is biased to the closed position by a light duty return spring (not shown).

Yet another aspect of piston assembly **110** is discharge check valve **118**. Discharge check valve **118** is for preventing hydraulic fluid in the high pressure volume **116** from entering the high pressure header **104** unless the pressure in volume **116** is higher than the pressure in header **104**. This operation allows for the fluid pressure in the header **104** to be maintained at a desired minimum level regardless of the operational state of the piston assembly **110**. Multiple configurations exist for discharge check valve **118** without departing from the concepts presented herein. In the embodiment shown in FIGS. **2-3** discharge check valve **118** is a ball valve disposed within an opening **117***a* of housing **117** and is biased to the closed position by a light duty return spring (not shown).

To prevent leakage in piston assembly **110**, a variety of seals **119** are located throughout the assembly. Seals **119** can be of any type suitable for use in high pressure hydraulic fluid applications.

In operation, hollow needle shaft **111** increasingly occupies the high pressure volume **116** of housing **117** as shaft **111** moves in the first direction as the cam lobe **108***a* forces the shaft **111** in this direction. As this occurs, pressure within the housing **117** continually increases, as the hollow portion **111***a* of shaft **111** is full of hydraulic fluid and vacuum check valve **112** is in the closed position. As stated previously, pressure within the housing **117** increases until the pressure becomes greater than the fluid pressure within the header **104**. At this point, discharge check valve **118** opens to allow hydraulic fluid to be moved into the header **104**. Once contact with cam lobe **108***a* is removed, hollow needle shaft **111** starts moving in the second direction by operation of the return spring **113***b*, discharge check valve **104** closes and vacuum check valve **112** opens, thereby allowing pumped hydraulic fluid to quickly enter the hollow portion **111***a* of the shaft **111** via header **102**, line **102***a*, low pressure volume **115** and inlet ports **113***d* in stem **113**. Once, shaft **111** reaches its full extension in the second direction, it remains available to be moved in the first direction again by cam lobe **108***a*.

It should be noted that the diameter of hollow needle shaft **111** is considerably smaller than the corresponding diameter of the housing **117** into which hydraulic fluid is further pressurized. This arrangement has specific benefits in that a relatively small force is required to move the reduced diameter shaft **111** in the first direction, as compared to an arrangement where the shaft diameter is increased to match that of the housing. By pumping a relatively small volume of fluid with each stroke of shaft **111**, the actuating force is decreased thereby allowing for the oscillating speed of the shaft **111** to be greatly increased. This allows for the plurality of piston assemblies **110** to easily deliver a steady stream of hydraulic fluid pressurized at 4,000 pounds per square inch (psi) and potentially beyond 50,000 psi. Additional, though smaller, advantages of utilizing such an arrangement is increased heat dissipation by the larger housing walls and reduced turbulence in the high pressure volume, both of which can potentially increase the overall efficiency of the system. One example of a suitable arrangement is a shaft **111** having an outside diameter of ⅛ inch and a housing **117** having an internal diameter of 1¼ inch with a wall thickness of about ¾ inch. In such an arrangement, the force required to move the shaft **111** in the first direction can be as low as 10 pounds, depending upon the desired fluid pressure. In comparison, a piston having a surface area of one square inch would require 4,000 pounds of force to generate the same fluid pressure. Thus, the use of the ⅛ inch hollow needle shaft can produce the same pressure as a 1 inch shaft, but at a piston force of 100 times less. A similar mechanical advantage can also be obtained by increasing the size of the housing **117** relative to the shaft **111**.

It should also be noted that the plurality of piston assemblies shown in FIG. **1** can have varying diameters for shaft **111**. Additionally, rotary actuator **108** can also be configured to selectively engage piston assemblies **110** having a particular shaft **111** diameter. In such a configuration, the rotary pressure production device **100** can engage only the piston assemblies **110** having larger shaft diameters to quickly build up a high volume of pressurized hydraulic fluid. This mode of operation is preferable during start up or regeneration when initial hydraulic fluid pressure is relatively low. As the hydraulic fluid pressure increases, the rotary pressure production device **100** can engage piston assemblies **110** having smaller shaft diameters in order to elevate the hydraulic fluid pressure further to a desired value.

Referring back to FIG. **1**, another aspect of the overall system is high pressure fluid storage system **200**. High pressure fluid storage system **200** is for storing pressurized hydraulic fluid produced by the rotary pressure production device **100** such that the fluid can be used independently of the operation of the rotary pressure production device **100**. Various configurations exist for high pressure fluid storage system **200** without departing from the concepts herein. The following paragraphs describe various aspects and features of high pressure fluid storage system **200** which is piped into the larger system via lines **200**A and **200**B.

In a first embodiment shown at FIGS. **4**A, **4**B, **4**C, fluid storage system **200** includes an aspirated accumulator **202** and a gas concentrator **220**. As shown, accumulator **202** has a spherical shell **204** with a diaphragm wall **206** that divides the accumulator **202** into a hydraulic fluid volume **208** and a gas volume **212**. Although a spherical shape for shell **204** is shown for its inherent burst resistance and minimal space occupancy, many other shapes for accumulator **202** are possible. The gas volume **212** is in fluid communication with concentrator **220** via conduit **218** which wraps about shell **204** multiple times to increase the volume of stored gas and to increase the burst resistance of the accumulator shell **204**. Although only one winding revolution is shown on the drawings for the purpose of clarity, multiple revolutions about shell **204** are contemplated. The concentrator **220**, which is shown as a hollow spherical shell, is in fluid communication with gas compressor **134**. The hydraulic fluid volume **208** is in fluid communication with the rotary pressure production device **100**, the hydraulic motors **132***a*, **134***a*, **136***a*, and the pressure reducing valve **124**.

In operation, gas compressor **134** is activated to pre-pressurize the gas volume **212** of the accumulator **202** via lines **200**B and **218**. This pre-pressurization ensures that any hydraulic fluid stored within the accumulator **202** will be held at or above the minimum operating pressure for each of the hydraulic motors **132***a*, **134***a*, **136***a*. In some applications, the gas volume **212** will be pre-pressurized to 2,000 psi. FIG. **4**C shows the accumulator **202** in a fully pre-pressurized state with a minimum volume of hydraulic fluid. To prevent a possible rupture in the diaphragm, normally open check valve **216** is provided which closes upon contact with the diaphragm **206**. As pressurized hydraulic fluid pressure increases in the system via line **200**A, check valve **216** is forced open and the diaphragm **206** is increasingly moved such that the hydraulic fluid volume **208** increases and the gas volume **212** decreases. FIG. **4**A shows the diaphragm **206** in a neutral position wherein the gas volume **212** and the hydraulic fluid volume **208** have an equal volume. FIG. **4**B shows accumulator **202** in a maximum hydraulic fluid storage state wherein a possible rupture in the diaphragm is prevented by the operation of normally open check valve **214** which closes flow from conduit **218** upon contact with the diaphragm **206**.

It should be noted that, without concentrator **220** and conduit winding **218**, any incremental increase in pressure arising from additional hydraulic fluid entering the hydraulic fluid volume **208** would cause a corresponding, equal rise in pressure in the gas in the gas volume **212**. Additionally, with the volume decreasing by half in the gas volume **212**, the pressure in the hydraulic fluid volume **208** will double. This circumstance can result in very rapid pressure swings in accumulator **202** which is undesirable. By adding additional gas volume to the gas volume **212**, these pressure swings can be reduced and the average pressure in the hydraulic fluid volume **208** can be stabilized. This is accomplished through conduit winding **218** and concentrator **220**. Further, concentrator **220** also aids in stabilizing pressure within conduit winding **218** which can be susceptible to rapid pressure loss without an additional volume of gas to draw upon. As a result, the disclosed system can be configured to, for example, ensure that the hydraulic fluid pressure in accumulator **202** is held between 2,000 psi and 4,000 psi while significantly more than doubling the initial minimum amount of hydraulic fluid stored in the hydraulic fluid volume **208**.

A second embodiment of a high pressure fluid storage system **200** is shown in FIGS. **5A-5C**. This embodiment shares many of the same features as that described for the embodiment shown in FIGS. **4A-4C**. Therefore, the above description for the embodiment of FIGS. **4A-4C** is incorporated in its entirety for the embodiment of FIGS. **5A-5C**. The primary difference for the embodiment of FIGS. **5A-5C** is that two accumulators **202**, **202***a* are utilized instead of the single accumulator **202** and the concentrator **220** of FIGS. **4A-4C**. In this embodiment, both accumulators **202**, **202***a* are piped in parallel to lines **200A** and **200B** and function simultaneously in the same way as described for accumulator **202** in FIGS. **4A-4C**. However, accumulator **202***a* has a valve **210** that can be used to isolate accumulator **202***a* from the system, if desired. Additionally, although accumulator **202***a* is depicted as being smaller than accumulator **202***a*, the relative size of the accumulators can be adjusted to optimize the operation of the high pressure fluid storage system **200** in a variety of different applications.

For the accumulators **202**, **202***a*, the diaphragm **206** may be oriented in various physical arrangements. The orientation shown in FIGS. **4A-5C** is schematic and is not intended to represent any particular physical arrangement. One orientation that can be advantageous is to orient the accumulator(s) **202**, **202***a* such that diaphragm **206** is horizontal and the hydraulic fluid volume **208** is above the gas volume **212**. Over time, hydraulic fluid can saturate some membrane materials for diaphragm **206** and permeate into the gas volume **212**. By placing the hydraulic fluid volume **208** above the gas volume **212**, any permeated hydraulic fluid will collect at the bottom of the gas volume **212** of housing **202** where it can be easily drained away via check valve **214** or any other suitable device. Alternatively, or in conjunction with the above arrangement, the membrane material for diaphragm **206** can be chemically treated to increase resistance to membrane saturation penetration.

FIGS. **6-8** represent an alternative system in which pressurized hydraulic fluid is produced, stored and utilized. This system shares many of the same features as that described for the embodiments shown in FIGS. **1-5C**. Therefore, the above description for the embodiments of FIGS. **1-5C** is incorporated in its entirety for the embodiment of FIGS. **6-8**. The discussion of the embodiment shown in FIGS. **6-8** here is generally limited to the differences between the embodiment of FIGS. **6-8** and FIGS. **1-3**. The primary difference being the configuration of the rotary pressure production device **200** and the piston assemblies. Instead of having a low pressure header and feed pump, the system of FIGS. **6-8** relies upon atmospheric pressure to draw hydraulic fluid into the hollow needle shaft **111'** from an atmospheric reservoir **102'** within which rotary actuator **108'** is disposed. The hydraulic fluid can be maintained within reservoir **102'** by a flexible boot (not shown). Because of this atmospheric configuration, the piston assemblies **110'** are also configured differently in a few aspects. First, hollow needle shaft **111'** penetrates into the reservoir **102'** and is directly connected to strike head **113***c'* thereby eliminating the need for stem **113** and housing **114**. This configuration allows for inlet port **113***d'* to be installed directly into the shaft **111'**. As stated previously, more than one inlet port **113***d'* is advantageous for decreased flow resistance. Another difference is in the specific construction of vacuum check valve **112'** and discharge check valve **118'**. Vacuum check valve **112'** is located at the discharge end of shaft **111'** and is a reed type valve rather than a ball valve. Discharge check valve **118'** is also a reed type valve as well. As stated previously, many types of valves are possible for use in this application without departing from the concepts presented herein. Yet another difference is strike head **113***c'* which is shown as being stationary in comparison to the rotating wheel configuration of strike head **113***c*. It should be noted that any of the embodiments of the high pressure fluid storage system **200** are equally applicable for the system depicted in FIGS. **6-7** as they are for that depicted in FIGS. **1-3**.

Referring to FIG. **8**, an alternative system for actuating piston assembly **110** is shown that is particularly useful for regenerative braking applications in a vehicle drive train. Rather than causing the needle hollow shaft **111** to move through the use of cam lobes **108***a* and return spring **113***b*, the mechanism of FIG. **8** utilizes a rocker arm assembly **300**. Rocker arm assembly **300** is for moving the hollow needle shafts **111** of the piston assemblies **110**, via solid stem **113** in both the first direction **111***b* and the second direction **111***c* through the use of coupled rocker arms **302**, **304**. Rocker arm **302** is coupled at one end **302***a* to a piston assembly **110** while rocker arm **304** is coupled at one end **304***a* to an oppositely arranged piston assembly **110**. Thus, when the end **302***a*, **304***a* of the rocker arms **302**, **304** move, one piston assembly **110** is moved in the first direction **111***b* while the other is moved in the second direction **111***c*. Thus, as long as rocker arms **302**, **304** are moving, at least one piston assembly **110** is producing pressurized hydraulic fluid at any given moment. Rocker arms **302**, **304** are also coupled together by a crossbar **306** and arranged such that they can be actuated by a rotary actuator **308**. Rotary actuator **308** has undulating lobes **308***a* which cause a second end **302***b*, **304***b* of the rocker arms **302**, **304** to be displaced which causes an opposite displacement at ends **302***a*, **304***a*. Rotary actuator is mounted to drive assembly **310** via shaft **312** and may be driven by a motor or by the drive train of a vehicle in a regenerative braking application through the use of gears, a belt drive, a chain drive, or any other drive method known in the art. As shown, a plurality of rocker arms **302**, **304** and piston assemblies **110** can be combined to produce a cumulative volume of pressurized hydraulic fluid.

The above are example principles. Many embodiments can be made. Additionally, as the figures of this application are all schematic in nature, many fittings, valves and other accessories that are required for an actual physical system are not shown. However, one having skill in the art will readily appreciate and understand that such components would be included in a fully constructed embodiment.

I claim:

1. A pressure production system for pressurizing a hydraulic fluid, the system comprising a rotary pressure production device comprising:

(a) a plurality of piston assemblies, each comprising:

i. a hollow needle piston shaft through which hydraulic fluid is moved from a low pressure volume to a high pressure volume as the piston shaft moves in a first direction;

ii. a high pressure header in fluid communication with the high pressure volume;

iii. a vacuum check valve in fluid communication with the low and high pressure volumes, the vacuum check valve being closed as the hollow needle piston shaft moves in the first direction and open as the hollow needle piston shaft moves in a second, opposite direction;

(b) a rotary actuator constructed and arranged to move each hollow needle piston shaft in the first direction;

(c) a discharge check valve in fluid communication with the high pressure volume and the high pressure header, the discharge check valve being open when the hollow needle piston shaft is moving in the first direction, and when fluid pressure in the high pressure volume exceeds fluid pressure in the high pressure header, the discharge check valve being closed when the hollow needle piston shaft is moving in the second direction;

(d) a first aspirated accumulator including:

i. a spherical shell;

ii. a diaphragm operably positioned within the spherical shell defining a gas volume and a hydraulic fluid volume, the hydraulic fluid volume being in fluid communication with the high pressure header;

iii. a compressed gas within the gas volume;

iv. a compressed gas conduit winding in fluid communication with the gas volume, the gas conduit winding being wound about the spherical shell;

v. a gas compressor to deliver compressed gas to the gas volume via the gas conduit winding.

2. The pressure production system of claim **1**, further comprising a concentrator in fluid communication with the gas volume.

3. The pressure production system of claim **1**, further comprising at least one check valve to prevent the diaphragm from rupturing.

4. The pressure production system of claim **3**, wherein one check valve is operably positioned within the hydraulic fluid volume and one check valve is operably positioned within the gas volume.

5. The pressure production system of claim **1**, further comprising a second aspirated accumulator piped in parallel arrangement with the first aspirated accumulator, the second aspirated accumulator including:

(a) a spherical shell;

(b) a diaphragm operably positioned within the spherical shell defining a gas volume and a hydraulic fluid volume, the hydraulic fluid volume being in fluid communication with the high pressure header;

(c) a compressed gas within the gas volume;

(d) a compressed gas conduit winding in fluid communication with the gas volume, the gas conduit winding being wound about the spherical shell; and

(e) a gas compressor to deliver compressed gas to the gas volume via the gas conduit winding.

6. The pressure production system of claim **5**, further comprising at least one check valve to prevent the diaphragms of the first and second aspirated accumulators from rupturing.

7. The pressure production system of claim **5**, wherein one check valve is operably positioned within the hydraulic fluid volume and one check valve is operably positioned within the gas volume of the first and second aspirated accumulators.

8. The pressure production system of claim **1** wherein fluid pressure in the first accumulator is maintained at no less than 2,000 psi.

9. The pressure production system of claim **5** wherein fluid pressure in the first and second accumulators is maintained at no less than 2,000 psi.

10. The pressure production system of claim **1**, further comprising an electric generator configured and arranged to be driven by the hydraulic fluid stored in the first aspirated accumulator.

11. The pressure production system of claim **5**, further comprising an electric generator configured and arranged to be driven by the hydraulic fluid stored in the first and second aspirated accumulator.

12. The pressure production system of claim **1**, wherein the rotary actuator is driven by an internal combustion engine.

13. The pressure production system of claim **5**, wherein the rotary actuator is driven by an internal combustion engine.

14. The pressure production system of claim **1**, wherein the rotary actuator is driven by a vehicle drive train in a regenerative braking application.

15. The pressure production system of claim **5**, wherein the rotary actuator is driven by a vehicle drive train in a regenerative braking application.

16. A method for pressurizing hydraulic fluid, the method comprising the steps of:

(a) drawing hydraulic fluid from a low pressure volume into a hollow needle piston shaft;

(b) using a rotary actuator to move moving the hollow needle piston shaft and the hydraulic fluid within the hollow needle piston shaft in a first direction and into a high pressure volume;

(c) closing fluid communication between the high pressure volume and the low pressure volume;

(d) compressing the hydraulic fluid in the high pressure volume with the hydraulic fluid in the hollow needle piston such that the fluid is moved into a common high pressure header, the high pressure header being in fluid communication with the high pressure volume and with a hydraulic fluid volume of an aspirated accumulator, the aspirated accumulator having a spherical shell, the spherical shell containing a gas volume separated from the hydraulic fluid volume by a diaphragm, the gas volume receiving compressed gas from a compressed gas conduit winding, the compressed gas conduit winding being wound around the spherical shell;

(e) moving the hollow needle piston shaft in a second direction opposite the first direction; and

(f) closing fluid communication between the high pressure volume and the high pressure header.

17. The method for pressurizing hydraulic fluid of claim **16**, wherein the steps are repeated continuously.

18. The method for pressurizing hydraulic fluid of claim **16**, wherein a plurality of hollow needle piston shafts repeat the steps of claim **18** continuously.

19. The method of pressurizing hydraulic fluid of claim **18**, wherein some of the hollow needle piston shafts compress the hydraulic fluid at different times than other hollow needle piston shafts.

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